# Manufacturing Systems Overview

Lecturer: Stanley B. Gershwin

http://web.mit.edu/manuf-sys

http://web.mit.edu/chuanshi/www/

# HP Printer Case

## Background

- In 1993, the ink-jet printer market was taking off explosively, and manufacturers were competing intensively for market share.
- Manufacturers could sell all they could produce. Demand was much greater than production capacity.
- Hewlett Packard was designing and producing its printers in Vancouver, Washington (near Portland, Oregon).

# HP Printer Case

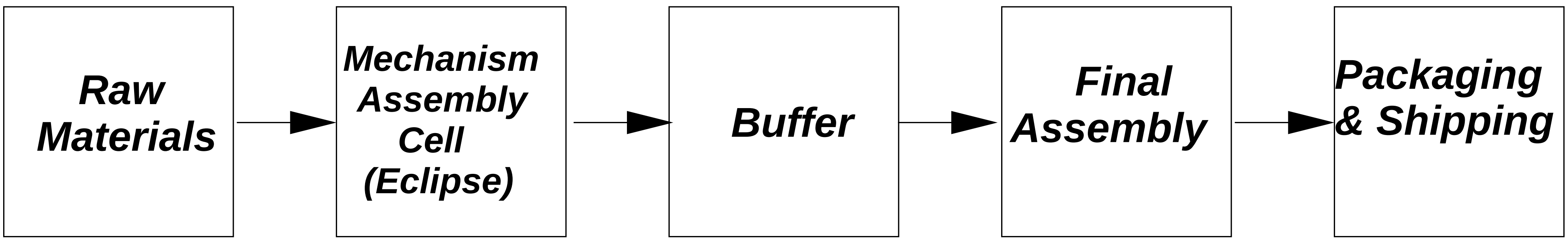
## Background

## HP's needs

- Maintain quality.
- Meet increased demand *and* increase market share.
  - ★ *Target: 300,000 printers/month.*
- Meet profit and revenue targets.
- Keep employment stable.
  - ★ *Capacity with existing manual assembly: 200,000 printers/month.*

# HP Printer Case

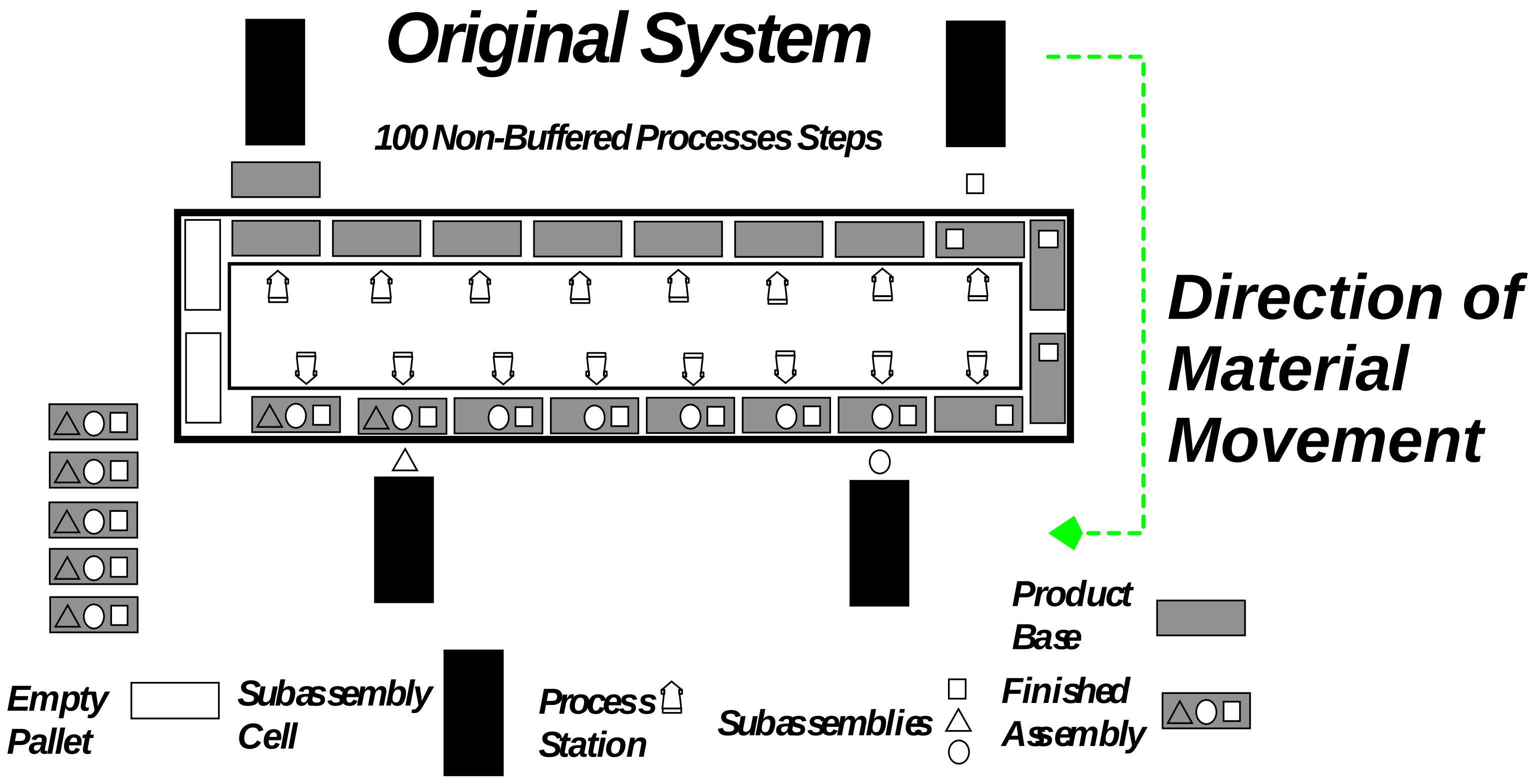
HP invested $25,000,000 in “Eclipse,” a new system for automated assembly of the print engine.




Two Eclipses were installed.

# HP Printer Case

## Printer Production




*Design philosophy:* minimal — essentially zero — buffer space.

# HP Printer Case

## The Problem

- Machine efficiencies[1] were estimated to be about .99.
- Operation times were estimated to be 9 seconds, and constant.
  - ⋆ Consequently, the total production rate was estimated to be about 370,000 units/month.
- BUT data was collected when the first two machines were installed:
  - ⋆ Efficiency was less than .99.
  - ⋆ Operation times were variable, often greater than 9 seconds.

*Actual production rate would be about 125,000 units/month.*

---

[1] *(to be defined)*

# HP Printer Case

## The Problem

- HP tried to analyze the system by simulation. They consulted a vendor, but the project appeared to be too large and complex to produce useful results in time to affect the system design.
  - *This was because they tried to include too much detail.*
- Infeasible changes: adding labor, redesigning machines.

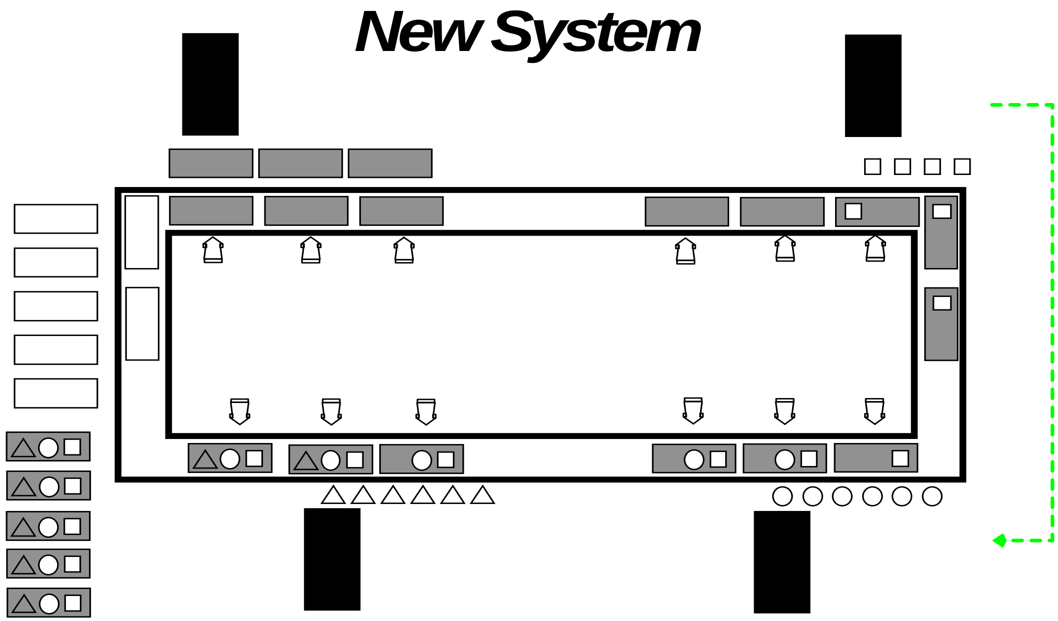
# HP Printer Case

## The Solution

- Feasible change: adding *a small amount* of buffer space within Eclipse.
- Design tools: *to be described in this course.*

# HP Printer Case

## The Solution




- Empty pallet buffer.
- WIP *work in process)* space between subassembly lines and main line.
- WIP space on main line.
- Buffer sizes were large enough to hold about 30 minutes worth of material. This is a small multiple of the mean time to repair (MTTR) of the machines.

# HP Printer Case

## The Consequences

- Increased factory capacity — to over 250,000 units/month.
- Capital cost of changes was about $1,400,000.
- Incremental revenues of about $280,000,000.
- Labor productivity increased by about 50%.
- Improved factory design method.
- New research results which have been incorporated in courses.
- MIT spin-off: Analytics Operations Engineering, Inc., `http://www.nltx.com/`.

# HP Printer Case

## Reasons for Success

- Early intervention.
- Rapid response by MIT researchers because much related work already done.
- HP managers' flexibility.
- The new analysis tool was fast, easy to use, and was at the right level of detail.

# Course Overview

## Message

- *Manufacturing systems can be understood like any complex engineered system.*
- *Engineers must have intuition about these systems in order to design and operate them most effectively.*
- *Such intuition can be developed by studying the elements of the system and their interactions.*
- *Using intuition and appropriate design tools can have a big payoff.*

## Course Overview

## Goals

- To explain important measures of system performance.
- To show the importance of random, potentially disruptive events in factories.
- To give some intuition about behavior of these systems.

# Goals

- To describe *and justify* some current tools and methods.

- But *not* to describe all current common-sense approaches.

# Problems

- Manufacturing System Engineering (MSE) is not as advanced as other branches of engineering.
- Practitioners are encouraged to rely on gurus, slogans, and black boxes.
- A gap exists between theoreticians and practitioners.

# Problems

- The research literature is incomplete,
  - ★ ... but practitioners are often unaware of what does exist.
- Terminology, notation, basic assumptions are not standardized.
- There is typically a separation of product, process, and system design.
  - ★ They should be done simultaneously or iteratively, *not* sequentially.

# Problems

- Confusion about objectives:
  - ★ *maximize capacity?*
  - ★ *minimize capacity variability?*
  - ★ *maximize capacity utilization?*
  - ★ *minimize lead time?*
  - ★ *minimize lead time variability?*
  - ★ *maximize profit?*
- Systems issues are often studied last, if at all.

# Problems

- Manufacturing gets less respect than it deserves.
  - ★ *Systems not designed with engineering methods.*
  - ★ *Product designers and sales staff are not informed of manufacturing costs and constraints.*
- Black box thinking.
  - ★ *Factories not treated as systems to be analyzed and engineered.*
  - ★ *Simplistic ideas often used for management and design.*

# Problems

Reliable systems intuition is lacking. As a consequence, there is ...

- Management by software
  - ★ *Managers buy software to make production decisions, rather than to aid in making decisions.*
- Management by slogan
  - ★ *Gurus provide simple solutions which sometimes work. Sometimes.*

# Observation

- *When a system is not well understood, rules proliferate.*
- This is because rules are developed to regulate behavior.
- But the rules lead to unexpected, undesirable behavior. *(Why?)*

- New rules are developed to regulate the new behavior.
- Et cetera.

# Observation

- A factory starts with one rule: *do the latest jobs first* .
- Over time, more and more jobs are later and later.
- A new rule is added: *treat the highest priority customers orders as though their due dates are two weeks earlier than they are.*
- The low priority customers find other suppliers, but the factory is still late.
- *Why?*

# Observation

## Example

### Why?

- There are significant setup times from part family to part family. If setup times are not considered, changeovers will occur too often, and waste capacity.

- Any rules that do not consider setup times in this factory will perform poorly.

- *For example, ... ?*

# Definitions

- *Manufacturing:* the transformation of material into something useful and portable.

- *Manufacturing System:* A manufacturing system is a set of machines, transportation elements, computers, storage buffers, people, and other items that are used together for manufacturing. These items are *resources.*

# Definitions

- *Manufacturing System:*
  - Alternate terms:
    - *Factory*
    - *Production system*
    - *Fabrication facility*
  - Subsets of manufacturing systems, which are themselves systems, are sometimes called *cells, work centers,* or *work stations* .

# Basic Issues

- Frequent new product introductions.
- Product lifetimes often short.
- Process lifetimes often short.

This leads to frequent building and rebuilding of factories.

*There is little time for improving the factory after it is built; it must be built right.*

# Basic Issues

## Consequent Needs

- Tools to predict the performance of proposed factory designs.
- Tools for optimal factory design.
- Tools for optimal real-time management (control) of factories.
- Manufacturing Systems Engineering professionals who understand factories as complex systems.

# Basic Issues

- Design Quality – the design of products that give customers what they want or would like to have *(features).*

- Manufacturing Quality – the manufacturing of products to *avoid* giving customers what they *don't* want or *would not* like to have *(bugs).*

This course is about manufacturing, *not* product design.

# Basic Issues

## Quantity, Quality, and Variability

- Quantity – *how much* is produced and *when* it is produced.
- Quality – *how well* it is produced.

In this course, we focus *mostly* on *quantity*.

*General Statement: Variability is the enemy of manufacturing.*

# Basic Issues

- Make to Stock (Off the Shelf):
  - items available when a customer arrives
  - appropriate for large volumes, limited product variety, cheap raw materials

- Make to Order:
  - production started only after order arrives
  - appropriate for custom products, low volumes, expensive raw materials

## Conflicting Objectives

# Basic Issues

- Make to Stock:
  - ⋆ large finished goods inventories needed to prevent stockouts
  - ⋆ small finished goods inventories needed to keep costs low

# Basic Issues

## Conflicting Objectives

- Make to Order:
  - ⋆ excess production capacity *(low utilization)* needed to allow early, reliable delivery promises
  - ⋆ minimal production capacity *(high utilization)* needed to to keep costs low

# Basic Issues

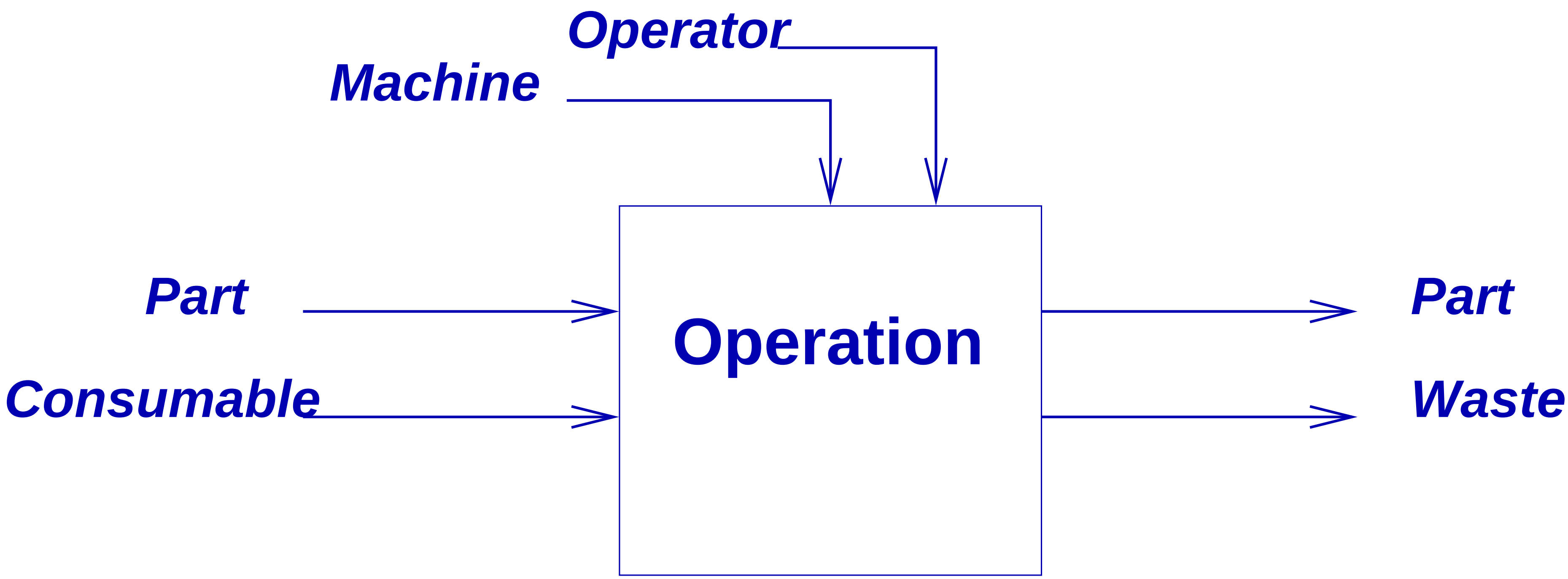
- *Complexity:* collections of things have properties that are non-obvious functions of the properties of the things collected.

- *Non-synchronism (especially randomness) and its consequences:* Factories do not run like clockwork.

# Basic Issues



## Operation




Nothing happens until everything is present.

# Basic Issues

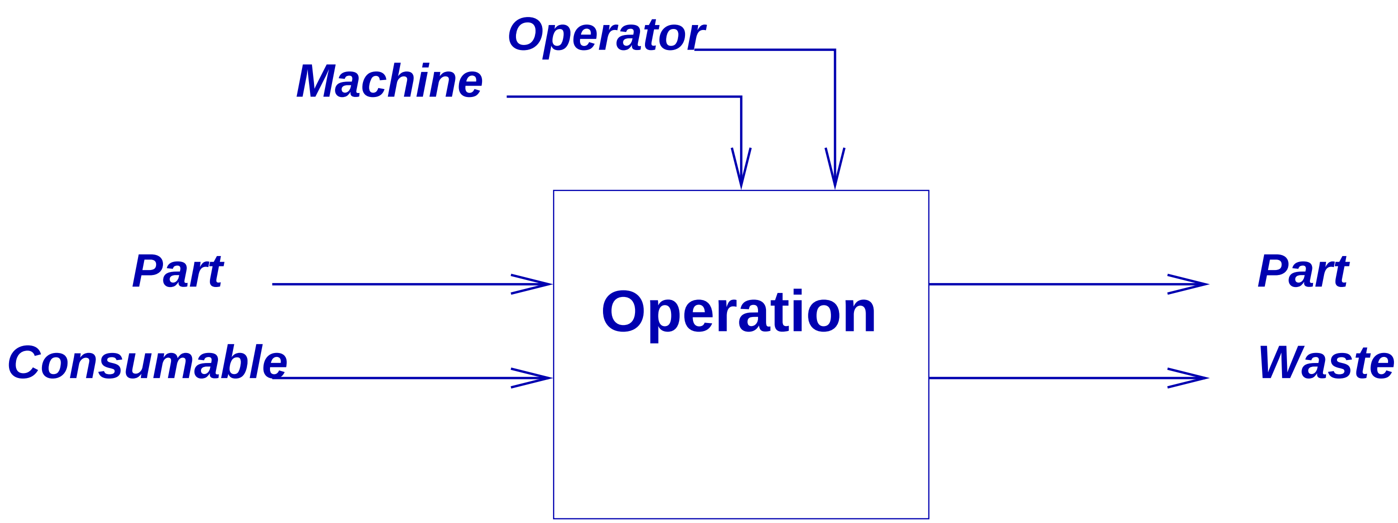
*Whatever does not arrive last must wait.*

- *Inventory:* parts waiting.
- *Under-utilization:* machines waiting.
- *Idle work force:* operators waiting.

# Basic Issues

## Concepts

### Waiting



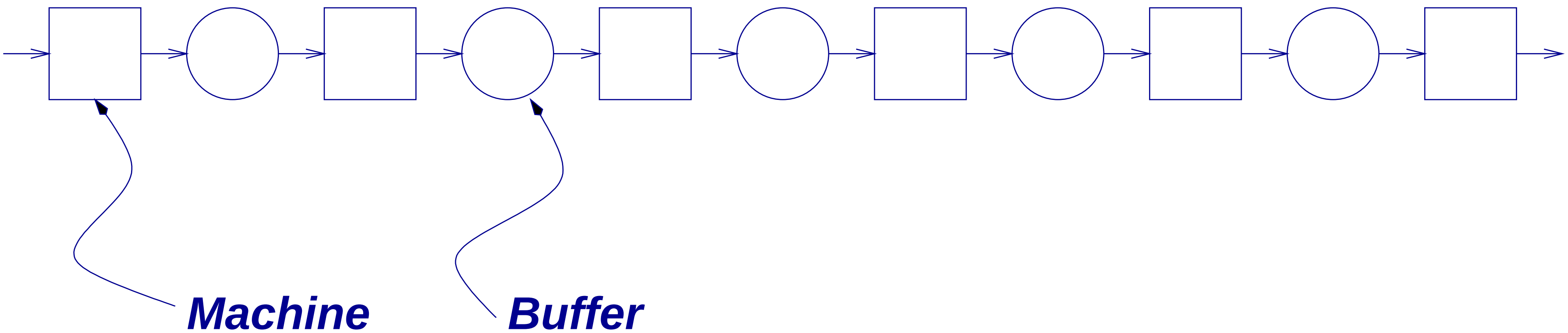

- *Reductions* in the availability, or ...
- *Variability* in the availability ...

... of any one of these items causes waiting in the rest of them and reduces performance of the system.

# Kinds of Systems

## Flow shop

... or *Flow line* , *Transfer line* , or *Production line.*

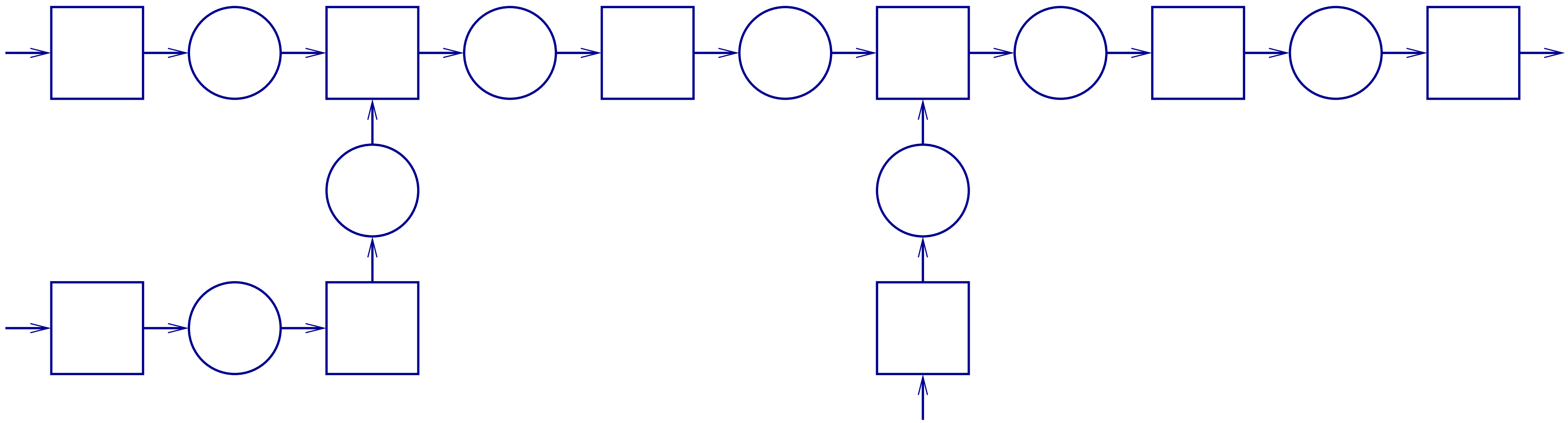



Traditionally used for high volume, low variety production.

*What are the buffers for?*

# Kinds of Systems

## Assembly system

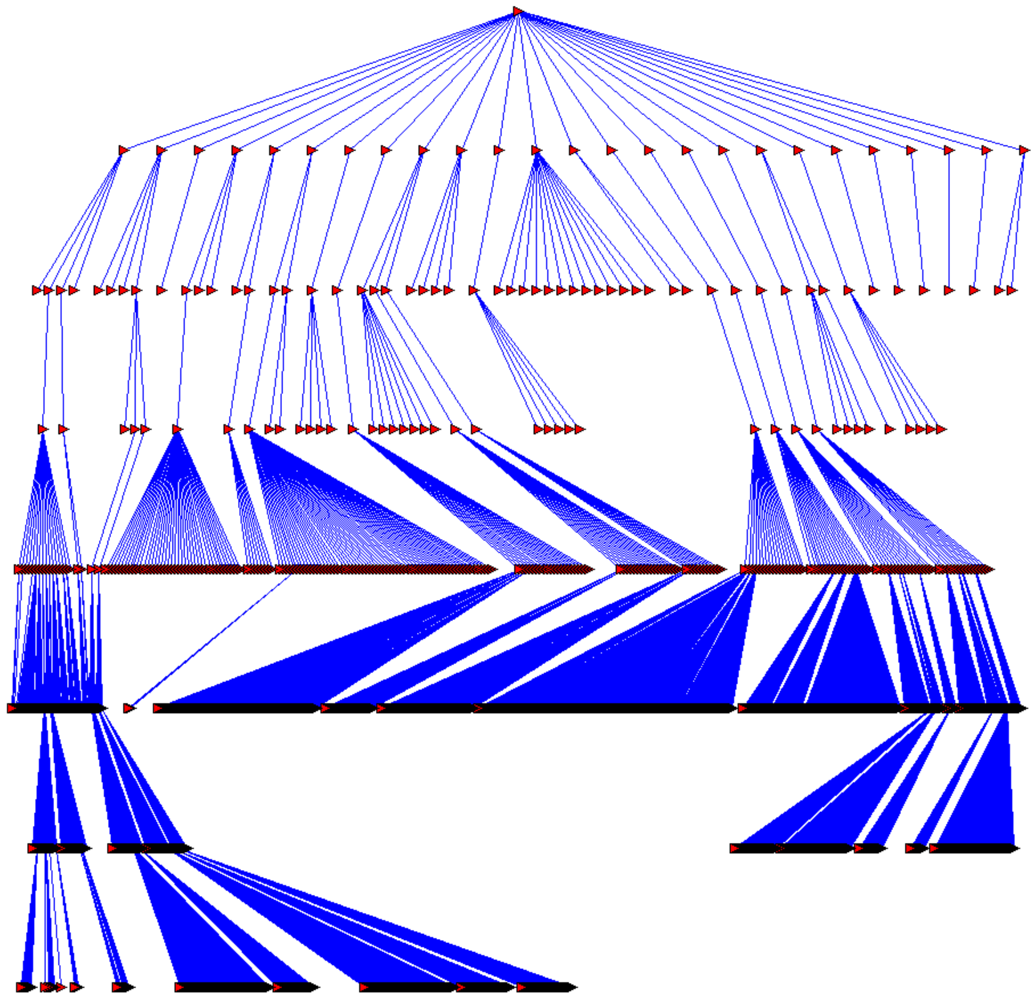


Assembly systems are *trees* , and may involve *thousands* of parts.

# Kinds of Systems

## Assembly system

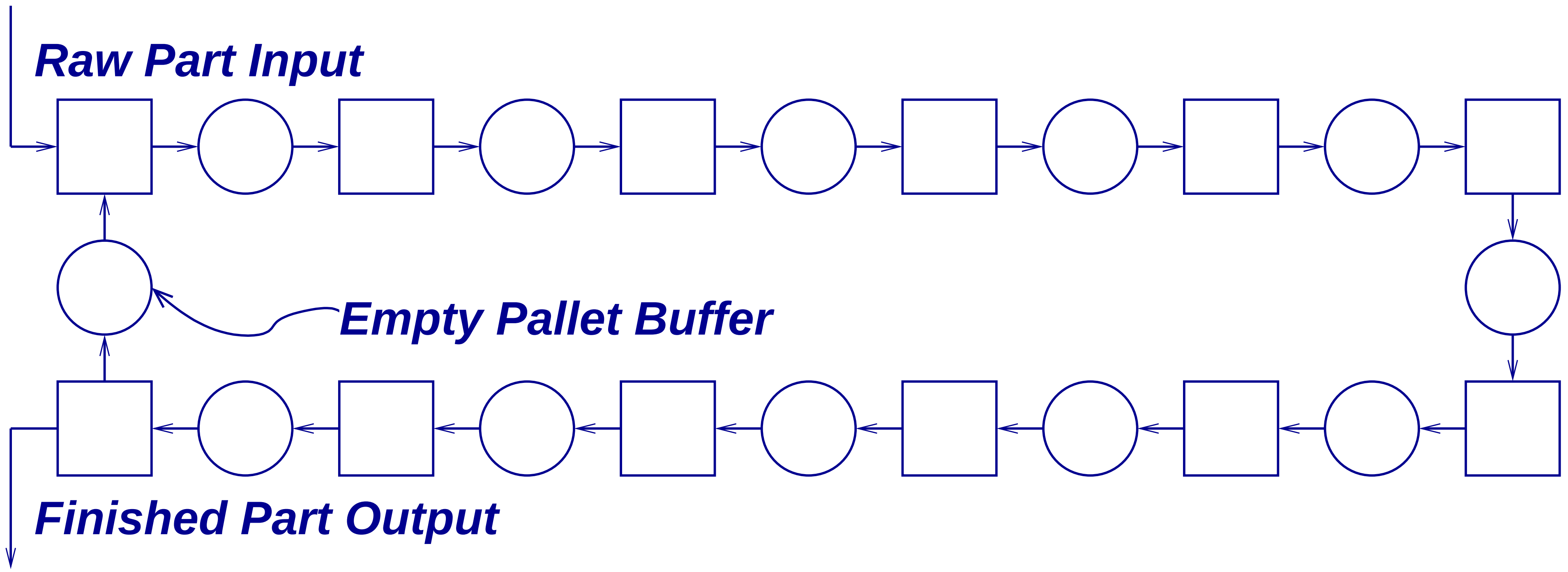
Bill of Materials of a large electronic product



# Kinds of Systems

## Loops

### Closed loop *(1)*



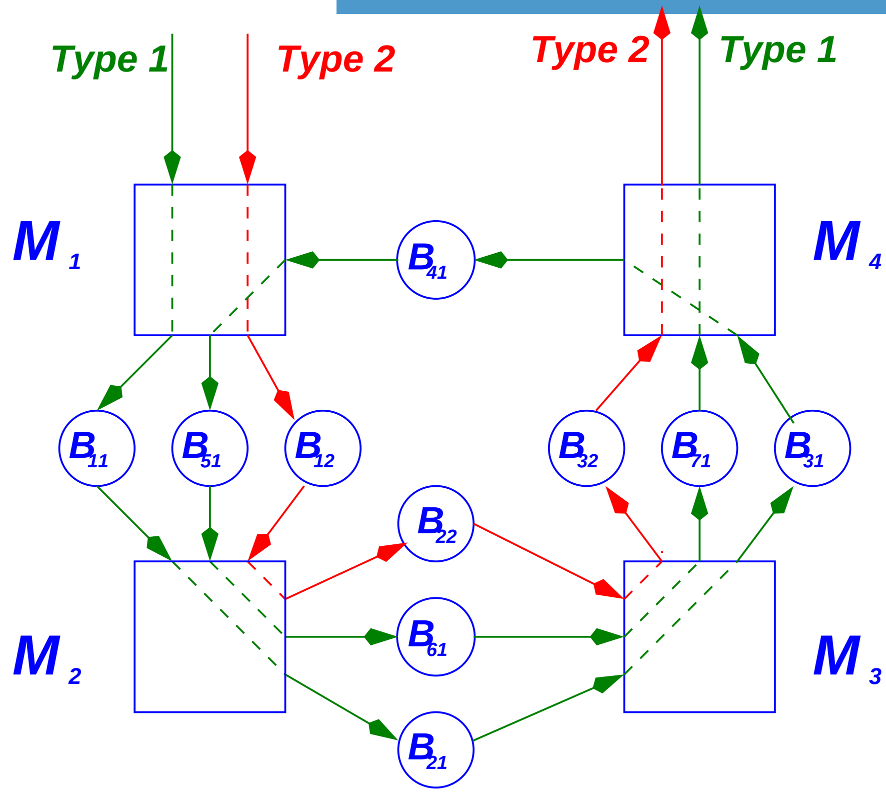

Pallets or fixtures travel in a closed loop. Routes are determined. The number of pallets in the loop is constant.

# Kinds of Systems

## Loops

### Reentrant loops *(2)*

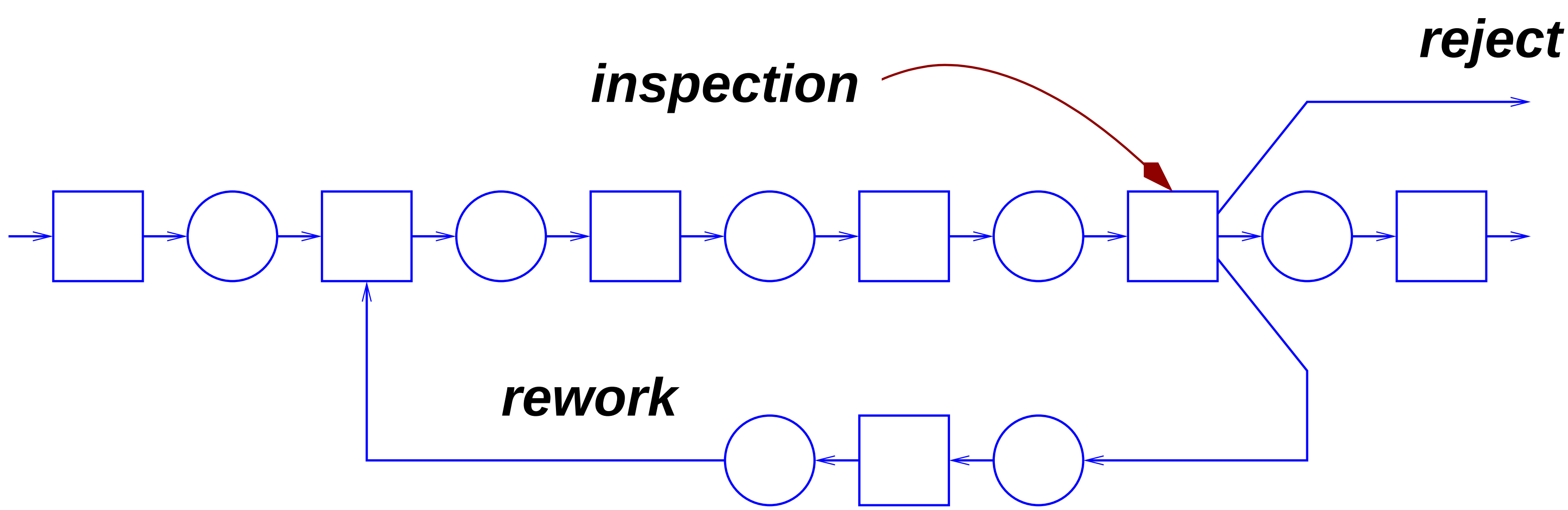
*System with reentrant flow and two part types*




Routes are determined. The number of parts in the loop varies.

Semiconductor fabrication is highly reentrant.

## Rework loop *(3)*




Routes are random. The number of parts in the loop varies.

# Kinds of Systems

## Job shop

- Machines not organized according to process flow.
- Often, machines grouped by department:
  - mill department
  - lathe department
  - etc.
- Great variety of products.
- Different products follow different paths.
- Complex management.

# Two Issues

- Efficient design of systems;
- Efficient operation of systems after they are built.

# Time

- All factory performance measures are about time.
  - ★ *production rate:* how much is made in a given time.
  - ★ *lead time:* how much time before delivery.
  - ★ *cycle time:* how much time a part spends in the factory.
  - ★ *delivery reliability:* how often a factory delivers on time.
  - ★ *capital pay-back period:* the time before the company get its investment back.

# Time

- Time appears in two forms:
  - delay
  - capacity utilization
- Every action has impact on both.

## Time

# Delay

- An operation that takes 10 minutes adds 10 minutes to the *delay* that
  - ★ a workpiece experiences while undergoing that operation;
  - ★ every other workpiece experiences that is waiting while the first is being processed.

# Time

- An operation that takes 10 minutes takes up 10 minutes of the available time of
  - a machine,
  - an operator,
  - or other resources.
- Since there are a limited number of minutes of each resource available, there are a limited number of operations that can be done.

## Time



- *Operation Time:* the time that a machine takes to do an operation.
- *Production Rate:* the average number of parts produced in a time unit. (Also called *throughput.* )

If nothing interesting ever happens (no failures, etc.),

$$\text{Production rate} = \frac{1}{\text{operation time}}$$

... but something interesting *always* happens.

## Capacity

- *Capacity:* the maximum possible production rate of a manufacturing system, for systems that are making only one part type.
  - *Short term capacity:* determined by the resources available right now.
  - *Long term capacity:* determined by the average resource availability.
- Capacity is harder to define for systems making more than one part type. Since it is hard to define, it is *very* hard to calculate.

# Randomness, Variability, Uncertainty

- *Uncertainty:* Incomplete knowledge.
- *Variability:* Change over time.
- *Randomness:* A specific kind of incomplete knowledge that can be quantified and for which there is a mathematical theory.

# Randomness, Variability, Uncertainty

- Factories are full of random events:
  - ⋆ machine failures
  - ⋆ changes in orders
  - ⋆ quality failures
  - ⋆ human variability
- The economic environment is uncertain
  - ⋆ demand variations
  - ⋆ supplier unreliability
  - ⋆ changes in costs and prices

# Randomness, Variability, Uncertainty

Therefore, factories should be

- *designed* and *operated*

to minimize the

- *creation, propagation,* or *amplification*

of uncertainty, variability, and randomness.

# Randomness, Variability, Uncertainty

- Therefore, all engineers should know probability...
  - ★ *especially manufacturing systems engineers* .